PHYSICAL REVIEW LETTERS

VOLUME 5 SEPTEMBER 1, 1960 NUMBER 5

EVIDENCE OF THE NATURE OF ROTATING LIQUID HELIUM*

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(Received August 18, 1960)

Earlier experiments by Hall[1] and also by Walmsley and Lane[2] on the angular momentum content of rotating liquid helium II have involved measurements of torque required to set a vessel of liquid into equilibrium rotation. Integrating the resultant torque-time measurements over the angular acceleration (or deceleration) period yielded thereby a measure of the angular momentum acquired by the helium. Since furthermore an integration over the volume of the vessel was involved, such methods produced composite, over-all data.

The present method[3] permits investigating both the time and position dependence of liquid helium II circulation within a rotating vessel by suspending a movable Rayleigh disk device within such a system. Besides thus providing both instantaneous and local observations, the sensitivity of such a probe to individual fluid component motions permits in fact a still further resolution; the special case of zero response, for example, uniquely specifies <u>each</u> fluid component as stationary.

The liquid helium II sample investigated resides within a cylindrical shaped glass vessel (just under 5 cm inner diameter) rotated axially about the vertical; a small ($\frac{1}{2}$ mm) aperture at the lower (tip) extremity connects the region with the outer helium bath for filling purposes, etc. A "stationary support" is provided inside the container for the disk suspension system which, although not rotating, is equipped (rack and pinion) for position adjustment along the vessel radius. The disk probe (3-mm diameter) is suspended by a quartz fiber (torsion constant ~ 10^{-5} dyne-cm/deg) to present an angle of 45° to the rotational flow direction. Resultant angular deflections from equilibrium orientation (tending to turn the disk across the flow) are observed as displacements of a narrow light beam refected from the (silvered) disk surface and focused upon an optical scale. The present observations are for a vessel rotation rate of 2 rpm.

The results of this investigation include the following principal findings:

(a) A delay interval of several minutes elapses between setting the container suddenly into rotation from rest and initial response of the disk to the liquid helium II system. In contrast, the disk responds immediately to stopping rotation of the vessel. Thus liquid helium II appears to acquire a "rigidity" in rotation which is absent when stationary.

(b) A linear relationship between such delay interval and radial position of the disk indicates that the circulatory motion propagates as a "rotation front" slowly inward from the moving wall of the container with a definite velocity.

(c) Steady-state angular deflections, reached after roughly one-half hour buildup time from initial response, obey a parabolic dependence upon radial distance from the axis.

(d) Finally, steady-state deflections depend markedly upon temperature. Upon cooling through the λ point the apparent rotational flow drops abruptly from the helium I value to zero, indicating no circulation at all. With reduction of temperature further into the helium II region circulation reappears, however, and builds up mono-

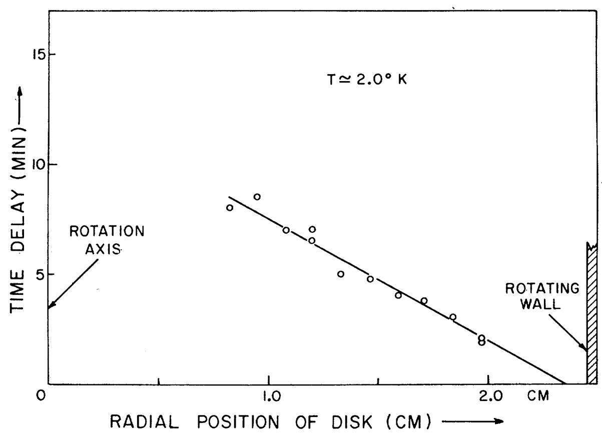

FIG. 1. Time delay versus disk location. The time interval (min) preceding initial response is plotted versus distance (cm) from rotation axis to midpoint of disk. Note location of intercept.

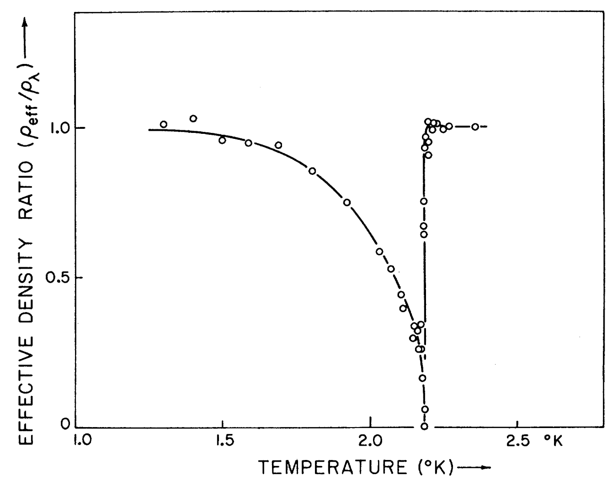

FIG. 2. Temperature dependence of fluid rotation. The effective density ratio (ρ_{eff}/ρ_λ), plotted versus temperature (°K) for a fixed disk location (1.84 cm from axis), represents the fraction of fluid carried into rotation with vessel. Note apparent rejection of fluid rotation upon cooling through λ point.

tonically to the helium I value toward the lower temperature limit ($T \to 1$°K).

The "rotation front" propagation phenomenon (b) is illustrated in Fig. 1, where response delay times (min) are plotted versus radial distance (cm) to the disk midpoint from the rotation axis. For a temperature of 2.0°K (and vessel rotation rate of 2 rpm), the observed slope indicates an apparent "rotation front" velocity radially inward of about 2 mm/sec. Furthermore, observation that the intercept (zero time lapse) falls inside the liquid helium region indicates the liquid "circulation front" first disturbs the extreme edge of the disk.

The unexpected temperature dependence (d) is illustrated in Fig. 2, where fluid circulation is plotted versus temperature (°K) for a fixed disk location (1.84 cm from axis of rotation). Observed results are expressed most directly as an effective density ratio (ρ_{eff}/ρ_λ), representing the fraction of fluid evidently carried into rotation with the vessel; the ratio measures the observed torque normalized to the helium I value (at the λ point). Clearly a marked dependence of temperature exists, characterized by a sharp drop evidently to zero circulation immediately below the λ point. A general (approximate) resemblance may be noted between this curve for effective density ratic and the well-known temperature dependence of superfluid concentration (ρ_s/ρ). Such behavior might be interpreted (but possibly oversimplified) to indicate that under these circumstances superfluid rotates whereas normal fluid does not.

Logical explanations for findings (a), (b), and (c) follow directly in principle from an application[4] of the Feynman concept[5] of rotating liquid helium II, based on migrating quantized vortex distributions. Observed temperature dependence of finding (d) appears unaccountable, however, on the basis of either theory or (previous) experiment. According to Feynman's theory[5] and Hall's measurements,[1] for example, indicating rotation of both fluid components with a containing vessel, no temperature effect might be expected. According to Walmsley and Lane's measurements,[2] on the other hand, indicating rotation of normal fluid alone, an increase of circulation with temperature might be anticipated. The actual observed behavior remains clearly oblique to such expectations. The possibility naturally exists at this juncture that some obscure phenomenon related to the method of measurement is responsible.

A paper now in preparation to describe fully the experiment and results will be submitted shortly.

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*Supported in part by the Alfred P. Sloan Foundation, Inc., and the National Science Foundation.

[1]H. F. Hall, Trans. Roy. Soc. (London) 250, 359 (1957).

[2]R. H. Walmsley and C. T. Lane, Phys. Rev. 112, 1041 (1958).

[3]The technique as such was described at the Hawaii American Physical Society meeting, prior to present findings [J. R. Pellam, Bull. Am. Phys. Soc. 4, 370 (1959)].

[4]R. P. Feynman (private communication).

[5]R. P. Feynman, Progress in Low-Temperature Physics, edited by J. C. Gorter (North-Holland Publishing Company, Amsterdam, 1955), Chap. II, Vol. 1.

FIRST-ORDER TERRESTRIAL ETHER DRIFT EXPERIMENT USING THE MÖSSBAUER RADIATION

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(Received June 3, 1960)

Despite the general acceptance of the special theory of relativity, the Fitzgerald-Lorentz contraction theory and its ability to account for previous experiments have persisted. In particular, the extension of the Fitzgerald-Lorentz contraction theory by Ives[1] appears to bring the contraction theory on a par with both the special and general theories of relativity. It has been pointed out[2] that this impasse may be resolved by astronomical observations and satellite experiments designed to detect a variation in the one-way velocity of light with direction in space. The existence of such an observed variation, which may be considered to be synonymous with the existence of an ether, is allowed by the Fitzgerald-Lorentz contraction theory but not by the special theory. This note proposes a terrestrial experiment which has considerable sensitivity when the Mössbauer radiation is used and which permits a first-order test for a variation in the velocity of light with direction in space.

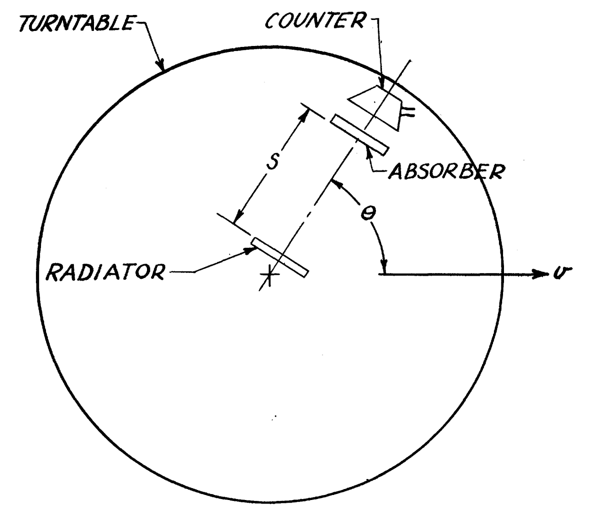

FIG. 1. Arrangement for the detection of a one-way variation in the observed velocity of light.

An electromagnetic radiator having a highly stable frequency, a frequency-selective absorber or filter, and a counter or other suitable detector are placed on a turntable, as shown in Fig. 1. Electrical connections to the counter or detector may be made through slip rings. If there is an ether and the velocity of the plane of the turntable through the ether is v, then the time taken for the radiation to travel the distance s between radiator and absorber is

$$\tau = \frac{s}{c - v\cos\theta}, \tag{1}$$

where c is the velocity of the radiation in the medium between radiator and absorber. When the table is rotated there is a variation in this time if $v \neq 0$. As the time varies there is a change, $-f d\tau$, in the phase of the radiation as received at the absorber, where f is the frequency of the radiation. The time rate of change of the phase corresponds to a change in frequency. The relative change in frequency at the absorber, when $v \ll c$, is then, to first order,

$$\frac{\Delta f}{f} = -\frac{d\tau}{dt} = \frac{\omega s v \sin\theta}{c^2} - \frac{v}{c^2}\frac{ds}{dt}\cos\theta - \frac{1}{c}\frac{ds}{dt}, \tag{2}$$

where ω is $d\theta/dt$, the angular velocity of the turntable. The last term is the Doppler shift. It and the second term may be minimized by using a rigid construction to insure that ds/dt is substantially zero.

If the linewidth of 1 part in 10^{12} achievable with the Mössbauer radiation[3] is used for detecting a minimum change in frequency, s is made $1/10^4$ km and is constant, and ω is 60π rad/sec, corresponding to 1800 rpm, then an ether drift of about 5 km/sec is measurable. With a "least count" sensitivity of 3 parts in 10^{16} estimated for the Mössbauer radiation[4] and the above values for s and ω, an ether drift of about 0.0015 km/sec is measurable.

The axis of the table may be located anywhere